Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: June 18, 1971

to: Distribution

from: G. S. Taylor

subject: Reissue of Memorandum:
Apollo 15 - Landing Mission
Possibilities Following a
TLI Underburn -- Case 310

The subject memorandum is reissued correcting the inadvertent substitution of semi-major axis length for apogee distance in the Abstract and Conclusion.

G. S. Taylor

2013-GST-jab

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(NASA-CR-119271) REISSUE OF MEMORANDUM - APOLLO 15 LANDING MISSION POSSIBILITIES FOLLOWING A TLI UNDERBURN (Bellcomm, Inc.) 10 p

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Bellcomm

955 L'Enfant Plaza North, S.W.
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date: June 9, 1971

to: Distribution

from: G. S. Taylor

subject: Apollo 15 - Landing Mission Possibilities Following a TLI Underburn -- Case 310

## ABSTRACT

With mission design modifications, the SPS can provide the capability to salvage a lunar landing for Apollo 15 launched on July 26, 1971 for TLI underburns of under 4.5 seconds and still maintain a LM rescue and weather avoidance $\Delta V$ contingency equal to or better than nominal. By allowing the sun elevation at landing to rise to 15.3°, a lunar landing with nominal contingency $\Delta V$ reserves can be achieved for an underburn of slightly over two seconds, which corresponds to an instantaneous elliptic orbit of 200,500 n.m. apogee. A lunar landing after a 3.5 second underburn (163,500 n.m. apogee) can be salvaged by lowering the landing approach azimuth to -96° and raising the sun elevation at landing to 16.7°. An additional second can be added to the salvage ability of either case if the post-ascent orbital stay is deleted. Thus the maximum interval of TLI underburn for which the landing mission can be salvaged and still possess nominal $\Delta V$ reserves is about 4.5 seconds and corresponds to an instantaneous elliptic orbit with an apogee of nearly 143,500 n.m. The sensitivity of end-of-mission $\Delta V$ to TLI underburns with these design modifications is approximately 200 fps/second of underburn.

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MEMORANDUM FOR FILE

If the SIVB shuts down prematurely during TLI, various options are available to nullify the effect of this underburn and still allow a lunar landing. This memorandum outlines the options available and their capability to compensate for a TLI underburn. For flexibility in application, the SPS $\Delta V$ margins are discussed relative to nominal levels.

## Method of Determining TLI Vector for Underburns

The TLI vector resulting from various underburns was approximated by allowing the magnitude of the velocity of the nominal TLI state vector (from Reference 2) to decrease by 50 fps for each second of underburn while the position and direction was held constant. Whereas the position can only change by about thirty-five nautical miles from the nominal position in the time interval under consideration, this approximation closely simulates the actual event.

## Time of Midcourse Correction

In order to salvage the lunar landing for an underburn, a midcourse correction must be performed at two hours after TLI or later. Figure 1, which displays the ratio of the SPS $\Delta V$ correction to the underburn deficit as a function of time after TLI, shows that the least expensive time to make this correction is at TLI + 2 hours. Therefore, all subsequent information is presented assuming the correction occurs at this time.

## Options to Salvage Landing

The midcourse correction at TLI + 2 hours that compensates for the TLI underburn reduces the SPS $\Delta V$ available for contingencies. Figure 2 shows the change in SPS contingency $\Delta V$ from the nominal mission reserves as a function of seconds of TLI underburn maintaining the nominal mission design. It is seen that a one-second underburn results in a loss of nearly 300 fps contingency SPS $\Delta V$. Noting that our LM rescue contingency $\Delta V$ for the nominal is less than 700 fps, it is necessary to deviate from the nominal mission characteristics to allow lunar landing to occur for TLI underburns. Three options are considered to increase the SPS $\Delta V$ reserves.

### A. Increase Sun Elevation at Landing

The first option is to allow the sun elevation at landing to increase. Figure 3 shows the resulting changes in the LM rescue and weather avoidance contingency $\Delta V$ from the nominal reserves for the case of optimum sun elevation and the case constraining the sun elevation to stay below the 15.8° elevation at which Goldstone coverage terminates. Figure 3 also relates underburn time with optimum sun elevation.

### B. Optimize Approach Azimuth

Figure 4 displays changes in available contingency SPS $\Delta V$ for TLI underburns if the approach azimuth at landing is allowed to optimize maintaining the sun elevation at 12°. The optimum value for the approach azimuth of the July 26, 1971 launch is -97.5°. This alternative is not as beneficial as allowing the sun elevation at landing to increase.

### C. Optimize Approach Azimuth and Sun Elevation

Optimizing both the approach azimuth and sun elevation for each second of underburn results in lower deficiencies as compared to the nominal SPS contingency $\Delta V$ values and thus is the option providing maximum SPS salvage capability. Figure 5 displays the resulting contingency $\Delta V$ characteristics of this option. Figure 5 also shows the corresponding optimum approach azimuth and sun elevation for each second of underburn.

## Conclusions

Using Figures 2-5, the length of underburn for which the SPS can salvage the lunar landing and still possess nominal reserves can be determined. Option 1, in which the sun elevation at landing is allowed to be optimum will allow the mission to be salvaged for underburns of slightly over 2 seconds ($\sim$15.8° sun elevation) if PDI coverage from Goldstone is maintained and only a fraction of a second more if the coverage is sacrificed. Allowing the approach azimuth to optimize while maintaining 12° sun elevation will allow lunar landings from underburns of approximately two seconds. Option 3, for which the sun elevation and approach azimuth are optimized for each second of underburn provides the capability of having a lunar landing for underburns of under 3.5 seconds. Thus to salvage this amount of underburn, corresponding to an instantaneous elliptic orbit with a 163,500 n.m. apogee, it is necessary to allow a sun elevation of about 16.2° and a landing approach azimuth of -96°. Furthermore, the fact that the LM rescue contingency $\Delta V$ curve is much higher than weather avoidance $\Delta V$ curve results in a maximum lunar landing salvage capability of about 4.5 seconds. This corresponds to an instantaneous elliptic orbit with apogee of approximately 143,500 n.m. and is achieved by dropping the post-rendezvous lunar orbit science and returning at the earliest TEI opportunity. Figure 3 also shows that by reducing the nominal end-of-mission $\Delta V$ requirements, additional capability can be gained at the rate of about .5 seconds/100 fps of reduction. The use of this procedure with the nominal weather avoidance $\Delta V$ of 350 fps (Reference 1) will result in only about a half second additional salvage capability.

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Attachments

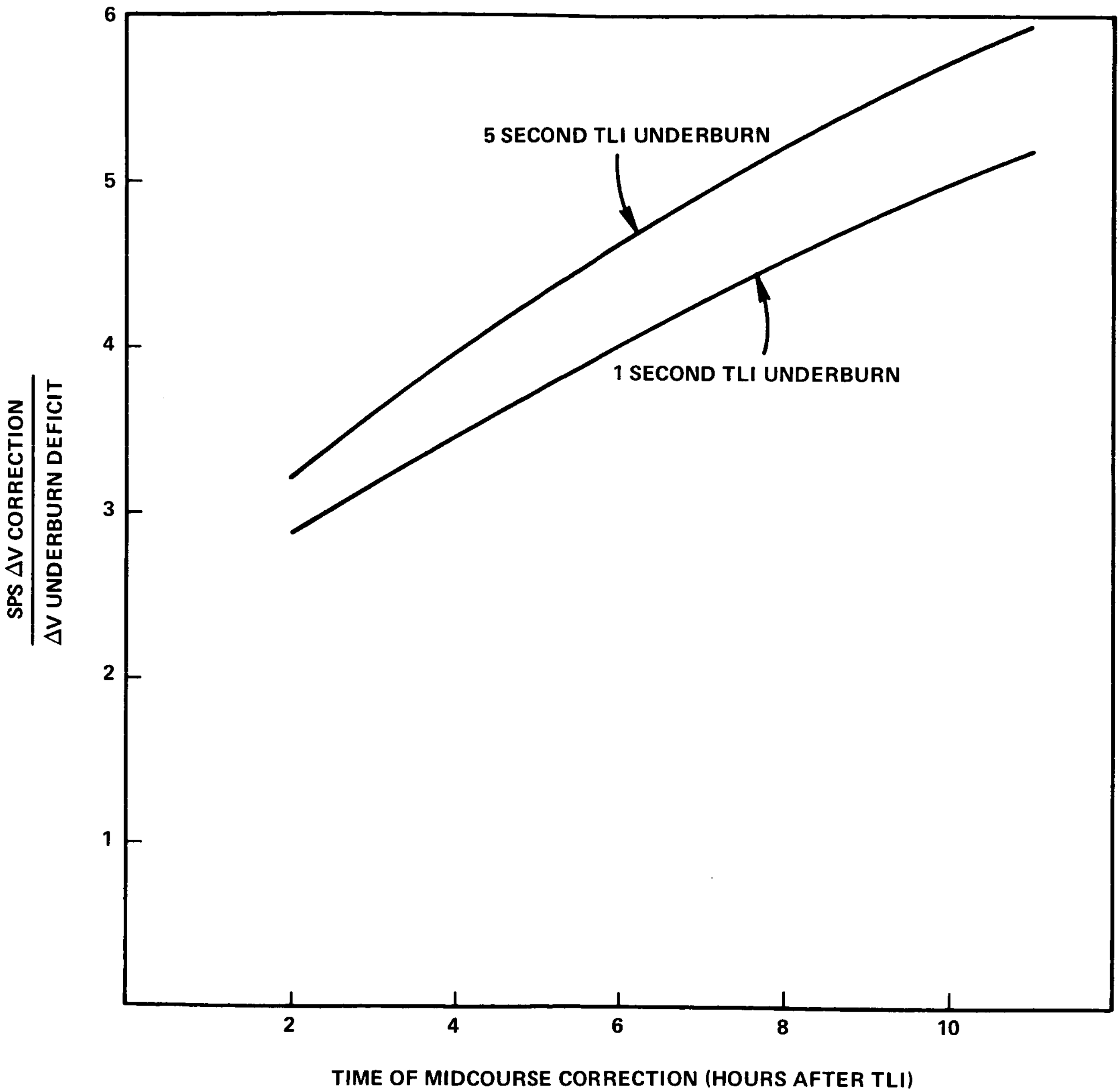


FIGURE 1 - RATIO OF MIDCOURSE CORRECTION ΔV TO ΔV UNDERBURN DEFICIT AS A FUNCTION OF TIME OF MIDCOURSE CORRECTION

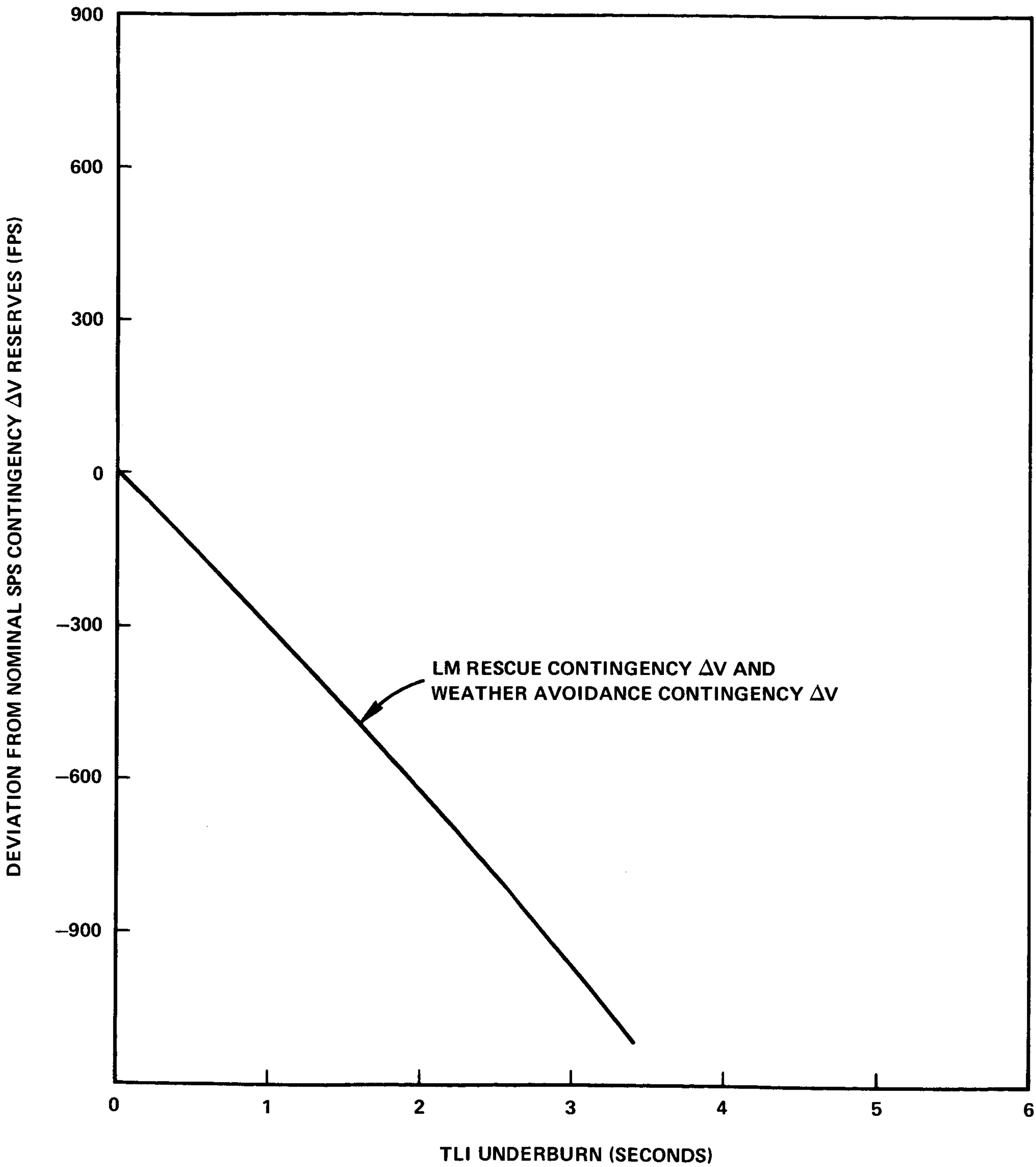


FIGURE 2 - DEVIATION IN CONTINGENCY ΔV FOR TLI UNDERBURN

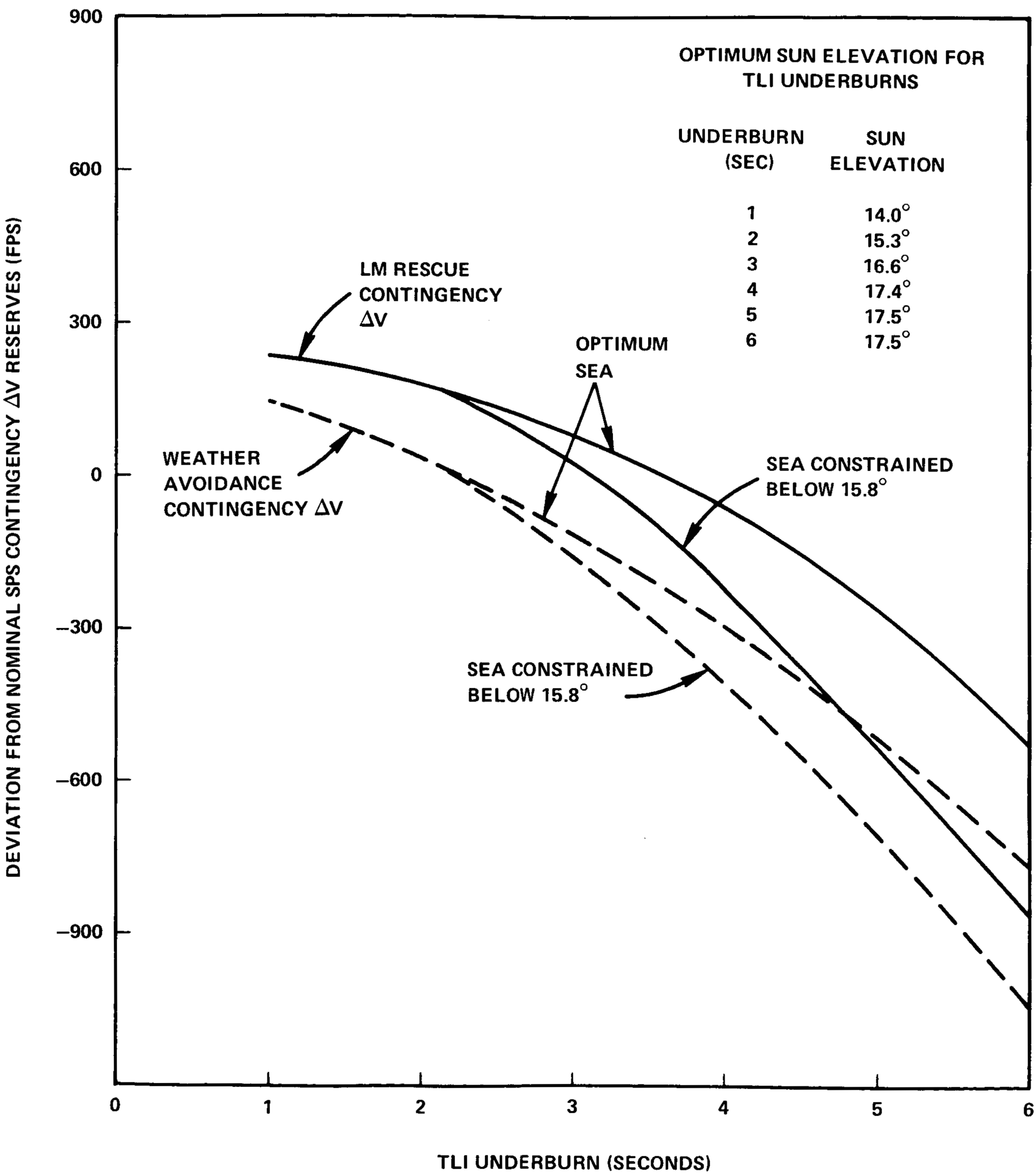


FIGURE 3 - OPTION 1 – OPTIMUM SUN ELEVATION

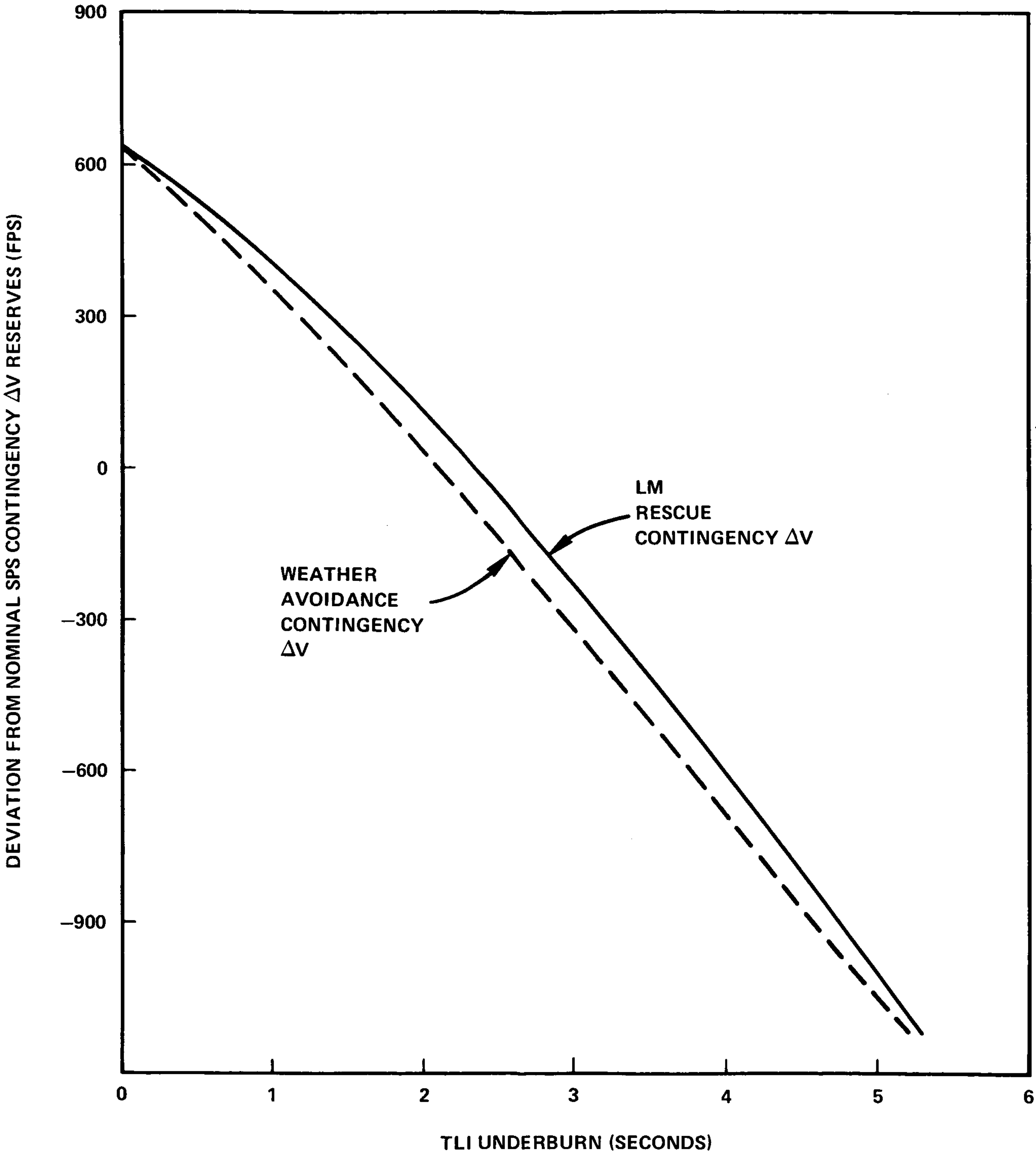


FIGURE 4 - OPTION 2 – OPTIMUM LANDING APPROACH AZIMUTH

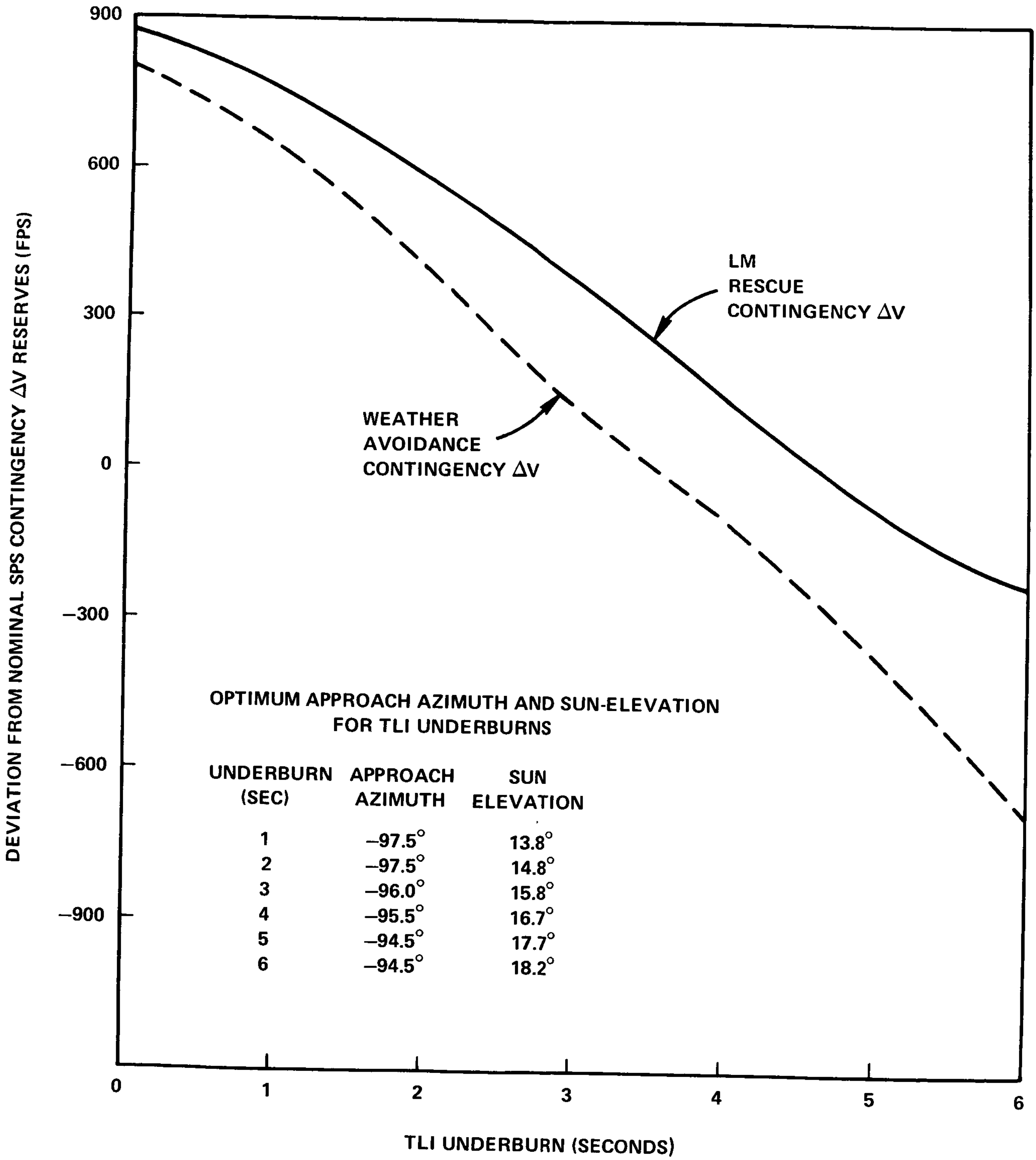


FIGURE 5 - OPTION 3 – OPTIMUM APPROACH AZIMUTH AND SUN ELEVATION